UNIVERSITY OF PENNSYLVANIA

SOIL ACIDITY, AN ECOLOGICAL FACTOR

ARTHUR PIERSON KELLEY

A THESIS

IN EDUCATION BOTANY

PRESENTED TO THE FACULTY OF THE GRADUATE SCHOOL IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

PHILADELPHIA
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SOIL ACIDITY, AN ECOLOGICAL FACTOR[1]

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INTRODUCTION

Since colorimetric methods were developed for the study of soil extracts there has been an increasing number of observations on the relation of the hydrogen-ion concentration of the soil extract to plant distribution. The general conclusion resulting from these studies has been that a soil of a particular locality has a more or less definite pH value and that plants found upon this soil are frequently those having a preference for that hydrogen-ion concentration.

These studies have been made frequently by testing the surface soil or that about living roots plucked from the soil. It seemed desirable to make a more intensive study of a particular region through a considerable length of time, taking into consideration the pH values of the subsoil and their relation to root distribution.

Subsoil acidity has not been without investigators. Wherry (13), working at Millsboro, Delaware, in March 1919, found that in digging down into sand beneath upland peat the acidity decreased markedly. Two years later Arrhenius (2), making borings about Bahtim and Giza in Egypt in some cases to a depth of 300 cm., found that the surface soil was alkaline but that the alkalinity decreased with depth; finding at Bahtim, however, an increase in pH values from surface to a certain depth followed by a decrease. Salisbury (10), in England, has also found a decrease in acidity of the subsoil of woodlands.

SOILS AND METHODS OF TESTING

A convenient locality was found in Chester County, Pennsylvania, about the village of Paoli. Within a radius of five miles there are five soil types with a number of diversified phases; Hagerstown (limestone), Chester (granitic), Manor (schistose), Dekalb (sandstone) and Conowingo (serpentine). A description of these soils and their location will be found in an earlier paper (6). Comparable areas were selected, representing as far as possible the average condition of that soil type and having as far as possible among themselves the same degree of slope, drainage and exposure. A large proportion of the tests were made in wooded regions which were as nearly in an undisturbed condition as could be found, while many tests were made in cultivated fields as well.

[1] A thesis presented to the Faculty of the Graduate School of the University of Pennsylvania in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Work was begun in November 1920. Originally only the surface soil was tested, by the colorimetric method described by Wherry (12). In the summer of 1921 it was decided to make careful tests on the subsoil. The soil auger used, consisted of a 1.5-inch wood auger the shaft of which was threaded and fitted to 50 cm. joints of gas-pipe and a handle. This could be carried conveniently in the field and could be operated to a depth of two metres, though this depth was not found except in Hagerstown loam.

In boring, care was taken that the samples should not be contaminated by soil of higher levels. A bit of the core from successive 15-cm. levels was pressed into a glass test-tube 100 x 15 mm. to a height corresponding to that of 5 cc. of water; the tube was corked and carried to the laboratory. Here distilled water (conductivity 2×10^{-6}) was added to a level equivalent to that of 15 cm. of water; the soil and water were then thoroughly stirred with a clean glass rod, and the suspension was allowed to settle, requiring usually from two to twelve hours. The entire interval between taking the sample and testing was seldom more than twenty-four hours.

Clear extracts could then be tested directly, using 1 cc. of the extract and comparing with standards as described by Clark and Lubs. Since the extracts were frequently turbid, a comparator was constructed by which the turbid extract might be compared with the standard which was screened by a similar turbid extract, viewed by electric light screened by blue glass. When very turbid the extract was diluted with distilled water to two or three times its volume, giving but a small error.

TABLE 1

Relation of productivity to soil reaction

SOIL TYPE	CHARACTERIZATION BY SOIL SURVEY	AVERAGE REACTION
		pH
Hagerstown	"exceptionally well adapted to crop production"	6.92
Chester	"well adapted to crop production"	6.53
Manor	"of considerable less value than Chester"	6.15
Dekalb	"not very productive"	5.71
Conowingo	"very poor"	5.38

RESULT OF SOIL TESTS

Surface soil tests had shown that a general average pH could be assigned to comparable areas of each loam, and these are given in table 1, together with a characterization of each soil made by the United States Department of Agriculture soil survey in 1906 (15). Correspondence between degree of fertility and pH value is evident.

Results of boring tests are given in table 2, in which the serial number of the test is given in the left-hand column, the depth in centimeters at the top and the average acidity at the bottom. Tests were not made closer than pH 0.1. All tests were made colorimetrically and have not been checked with the hydrogen electrode. Tests on Dekalb and Conowingo loams may be somewhat in error because indicators used with these soils were methyl red and cresol purple, which indicators are often not in agreement. Two indicators were always employed in testing and in some doubtful cases three.

Relations between average values determined from table 2 are made more evident by figure 1. It is seen at once that in most cases the curve does not

TABLE 2

Reaction of soil types studied

SERIAL TEST NUMBER	REACTION AT VARIOUS DISTANCES FROM SURFACE								
	Surface	15 cm.	30 cm.	45 cm.	60 cm.	75 cm.	90 cm.	105 cm.	120 cm.
	pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
	Hagerstown loam								
332	6.9	...	6.8	6.6	6.6	6.8	6.8	6.8	7.0
341	7.1	...	6.8	...	6.7				
454	7.0	...	6.4	6.6					
816	7.0	7.3	7.5	7.4	7.5	7.5	7.4	7.4	
824	7.0	7.4	7.3	7.3	7.5	7.4			
830	7.0	...	7.4	7.5	7.5				
735	7.0	6.7	7.2	7.2	7.0	7.0	7.1	7.2	
743	7.0	6.8	6.7	7.0	7.2	...	7.2	7.2	7.3
752	7.0	6.8	6.8	7.0	7.2	7.2	7.3	7.4	
882	7.1	7.0	7.0	7.2	7.0				
892	7.0	7.0	7.0	7.0					
897	7.0	6.5	...	7.0	7.0				
974	7.0	6.6	6.8	7.0	7.0				
990	7.0	6.5	6.0	6.2					
994	7.0	6.8	7.0	...	7.0				
999	6.6	5.8	6.4	6.6	6.6				
1004	6.8	6.4	6.8	6.8	7.0				
1009	6.5	6.5	5.8	6.0	6.2				
1019	7.3	6.9	7.0	7.1	7.0				
1024	7.2	6.8	7.0	7.0	6.9				
1029	7.0	6.8	6.9	6.9	7.0				
1220	7.4	6.8	7.1	6.4	6.8				
1225	7.3	7.4	7.3						
1228	7.3	7.2	7.3	7.4	7.4				
1226	7.2	6.2	6.5	6.5	6.5	7.0	7.0		
1273	7.0	6.6	...	6.8	7.0	7.0	7.0	7.0	
1281	6.6	6.4	7.0	7.3	7.4	7.0	7.0		
1335	6.4	6.0	6.0	5.8	5.8	5.9			
1341	6.4	6.0	6.0	6.0	6.0				
1346	6.2	6.0	5.8	6.0	6.0				
1381	7.0	...	6.8	6.7	7.0				
1439	6.8	6.8	6.5	6.5	6.5				
1444	6.8	6.6	6.5	6.5	6.5				
1449	6.8	6.8	6.6	7.0	7.0				
1553	7.0	7.0	6.8	7.0	7.0				
1568	7.0	6.6	6.6	7.0	7.0				
1558	6.7	6.5	6.6	6.8	7.0				
Av.	6.9	6.6	6.7	6.8	6.8	6.9	7.1	7.1	

SERIAL TEST NUMBER	REACTION AT VARIOUS DISTANCES FROM SURFACE								
	Surface	15 cm.	30 cm.	45 cm.	60 cm.	75 cm.	90 cm.	105 cm.	120 cm.
	pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
	Chester loam								
428	5.6	4.4	4.4	5.0					
433	...	4.4	4.4	5.1	5.2	5.1	5.8		
440	...	5.0	5.0	...	6.0				
499	6.2	6.4	6.4	6.4	6.4	6.4	6.0	6.2	
506	6.8	5.9	6.3	6.8	6.6				
511	7.0	6.2	6.2	...	6.2	...	...	6.6	
519	7.0	6.4	6.5	6.6					
523	7.0	6.4	7.0	6.4	6.4	6.6	6.8		
836	6.6	...	6.0	6.5	6.6				
841	6.8	6.2	6.3	6.4	6.8				
563	6.2	6.2	6.4	6.8					
568	6.8	...	6.4	6.4	6.6	6.5	6.5	6.6	
583	7.0	6.5	6.4	6.6					
587	7.0	...	6.5	6.1					
591	6.8	6.4	6.5	6.7	6.8	6.8			
607	5.8	5.4	6.0	6.1	6.1	6.1	5.8	5.8	
617	...	5.6	5.8	6.0	6.1	6.1	6.2		
624	6.5	5.4	5.8	5.9	6.1	5.8	6.0	5.8	
1031	6.5	5.6	6.2	5.8	6.1				
1035	6.5	5.6	5.8	5.8					
1039	6.5	5.6	6.5	6.8	7.0				
1044	6.8	6.0	6.1	6.2	6.2				
1049	7.0	6.6	5.6	6.4	6.8				
1054	6.5	6.2	6.4	6.4	6.2				
1049	6.2	6.0	6.4	6.5	6.6				
1064	6.0	5.6	5.8	6.0	6.2				
1070	6.0	5.8	5.5	5.6	5.6				
1075	5.5	5.4	5.6	5.6	5.7				
1080	7.0	6.1	7.0	6.9	6.8				
1085	6.8	6.8	6.3	6.4	6.8				
1090	6.5	6.6	7.0	7.0					
1246	6.8	6.2	6.2	6.3	6.4				
1251	6.0	6.1	6.2	6.3	6.4	6.6	6.6		
1258	6.9	5.8	6.1	6.1	6.1	...	6.4	6.5	
1317	6.2	5.4	5.6	5.6	6.1	6.0			
1323	6.4	5.6	5.8	6.0	6.0				
1329	5.6	5.7	5.8	5.8	6.0	6.0			
1409	6.5	5.4	5.4	5.4	5.6				
1414	6.4	...	5.8	5.6	6.0				

TABLE 2—*Continued*

SERIAL TEST NUMBER	REACTION AT VARIOUS DISTANCES FROM SURFACE								
	Surface	15 cm.	30 cm.	45 cm.	60 cm.	75 cm.	90 cm.	105 cm.	120 cm.
	pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Chester loam—Continued									
1419	6.3	6.3	6.2	6.0	6.0				
1484	7.0	6.8	6.8	7.0	7.0				
1489	7.0	...	6.8	6.8	7.0				
1494	7.0	6.8	6.9	6.9	7.0				
1568	6.8	6.2	6.7	6.8	6.8				
1573	7.0	6.6	6.5	6.7	6.8				
1578	6.1	5.8	6.4	6.8	...				
Av.	6.5	5.9	6.1	6.2	6.2	6.2	6.2	6.2	
Manor loam									
370	...	5.2	6.2	6.6	6.4				
375	6.0	6.2	6.2	6.6	6.4	6.6			
381	6.1	5.6	6.7	6.8	7.0	6.9	6.8		
388	...	...	5.2	5.0	5.0	5.0	5.0		
395	...	5.2	5.5	5.1	5.2				
400	...	4.7	4.7	5.0	5.0	5.2	5.4		
676	7.0	6.2	6.5	6.8	6.8	6.8	6.8		
686	6.8	5.6	6.6	6.8	6.8				
867	6.5	5.7	6.5	6.5	6.6				
872	6.4	5.8	6.6	6.8	6.5				
919	7.0	6.1	5.9	6.3	6.5				
924	7.0	6.1	5.9	6.3	6.5				
1094	5.2	5.0	5.0	5.1	5.1				
1099	5.8	5.2	5.0	5.0	5.0				
1106	5.6	5.5	5.7						
1114	6.2	5.8	6.4	6.5	6.5				
1119	6.6	6.5	6.0	6.0	6.4				
1134	5.1	4.8	4.9	4.9	5.2				
1301	5.4	5.6	6.1	6.1	6.2				
1306	5.4	5.1	5.3	5.4	5.5				
1311	5.6	5.5	5.7	5.9	6.1				
1366	5.8	5.4	6.0	6.0	6.0				
1371	5.8	...	6.5	6.5	6.5				
1376	6.1	6.1	6.0	6.0	5.8				
1454	6.7	6.2	6.6	6.9	6.8				
1459	6.6	6.2	6.9	6.9	6.8				
1464	6.6	6.4	6.8	6.8	6.8				
1579	6.8	6.4	6.6	6.6	6.8				
1584	6.6	5.8	6.0	6.8					
1588	5.8	6.0	6.0	6.2	6.4				
Av.	6.1	5.7	5.8	6.1	6.2				

SERIAL TEST NUMBER	REACTION AT VARIOUS DISTANCES FROM SURFACE								
	Surface	15 cm.	30 cm.	45 cm.	60 cm.	75 cm.	90 cm.	105 cm.	120 cm.
	pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Dekalb loam									
352	5.4	5.2	5.4	5.4	6.0				
472	5.8	5.8	6.0	6.2					
476	5.4	5.2	5.2	5.2	5.2	5.2			
487	5.9	6.2	6.4	6.4	6.4				
492	6.0	6.5	6.4	6.2	6.0				
710	6.1	5.7	5.6	5.6	5.8	5.7	6.0		
717	5.0	...	5.2	5.1	5.2	5.5			
723	5.0	5.6	5.4	5.2	5.2				
785	5.7	5.6	5.7	5.7	5.6	5.6			
792	5.6	5.4	5.4	5.8	5.8				
760	5.7	5.2	5.0	5.0	5.0	5.0	5.0		
767	5.6	5.0	5.0	5.0	5.4	5.7	5.6		
774	5.9	5.4	5.6	5.4	5.8	5.8	6.0		
781	5.6	5.4	5.6	5.7					
897	5.4	5.4	5.6	6.0	6.5				
902	5.3	5.4	5.9	6.1					
906	5.8	5.4	5.6	5.7	6.1				
911	6.1	6.6	6.6	6.4					
929	5.8	5.6	5.6	5.7					
934	5.4	6.0	6.2	6.4	6.5				
939	6.0	6.0	5.9	6.0	6.0				
944	5.8	6.0	5.0	5.6	5.7				
954	5.4	5.4	5.2	5.2	5.2				
959	5.8	5.8	6.0	6.0	6.0				
963	5.7	5.4	5.3	5.3	4.9				
968	5.8	5.4	5.8	6.1					
1207	6.0	6.0	6.3	6.4	6.2				
1212	6.3	6.1	6.3	6.4	6.4				
1311	5.6	4.9	4.9	5.2	5.2				
1356	5.6	5.2	5.0	5.1	5.2				
1361	5.6	5.4	5.4	5.8	5.6				
1396	5.7	5.3	5.3	5.4	5.6				
1401	5.7	5.3	5.3	5.3	5.5				
1406	6.1	5.4	5.4	5.5	6.1				
1429	6.1	5.4	5.4	5.7	5.7				
1434	6.1	6.4	5.4						
1593	5.4	5.8	6.0	6.2	6.4				
1598	6.2	6.4	6.4	6.6	6.6				
1603	5.8	6.0	5.6	6.4	6.6				
Av.	5.7	5.6	5.6	5.7	5.7				

TABLE 2—*Concluded*

SERIAL TEST NUMBER	REACTION AT VARIOUS DISTANCES FROM SURFACE								
	Surface	15 cm.	30 cm.	45 cm.	60 cm.	75 cm.	90 cm.	105 cm.	120 cm.
	pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
Conowingo loam									
418	4.6	4.8	5.0	5.8					
422	4.6	4.4	5.6	5.8					
549	5.4	5.4	5.6	5.8	6.2				
557	5.4	6.2	6.1	6.2	6.4	6.4			
530	5.6	5.6	5.8	6.1	6.2	6.1			
541	5.6	5.6	5.8	6.1					
549	5.4	5.4	5.6	5.8	6.2				
557	5.4	6.2	6.1	5.8	6.4	6.4			
632	5.1	5.0	5.2	5.2	5.7	5.8			
639	5.4	4.9	5.2	...	5.8	6.0			
646	6.0	5.8	5.8	5.8	6.2				
653	5.8	5.4	6.2	6.4	6.4	6.6			
659	6.0	6.0	6.4	6.4	6.1	6.1			
847	5.0	5.6	5.7	5.8	6.0				
857	5.0	5.4	5.6	5.8	6.2				
1139	5.2	5.6	6.0	6.5	7.0				
1144	5.4	5.8	5.8	6.0	6.2				
Conowingo loam—Continued.									
1149	5.8	6.0	6.0						
1152	4.8	5.0	6.0	6.5	6.2				
1157	5.0	4.8	5.0	5.0	6.0				
1162	5.6	5.6	5.8	6.0					
1166	6.1	5.7	6.5	6.5	6.5				
1171	5.2	5.6	5.8	5.6	6.0				
1233	5.4	5.8	6.0	6.0	6.3				
1238	6.1	4.4	5.1	5.3	5.3	5.5			
1294	5.2	...	5.3	5.5					
1469	5.4	5.6	5.8	5.8	5.8				
1474	5.4	5.0	5.6	5.8	5.8				
1608	5.4	6.2	6.4	6.4	6.4				
1613	5.8	5.9	6.0	6.4					
1617	4.8	5.4	5.8	6.2	6.4				
Av.	5.3	5.4	5.7	5.9	6.5				

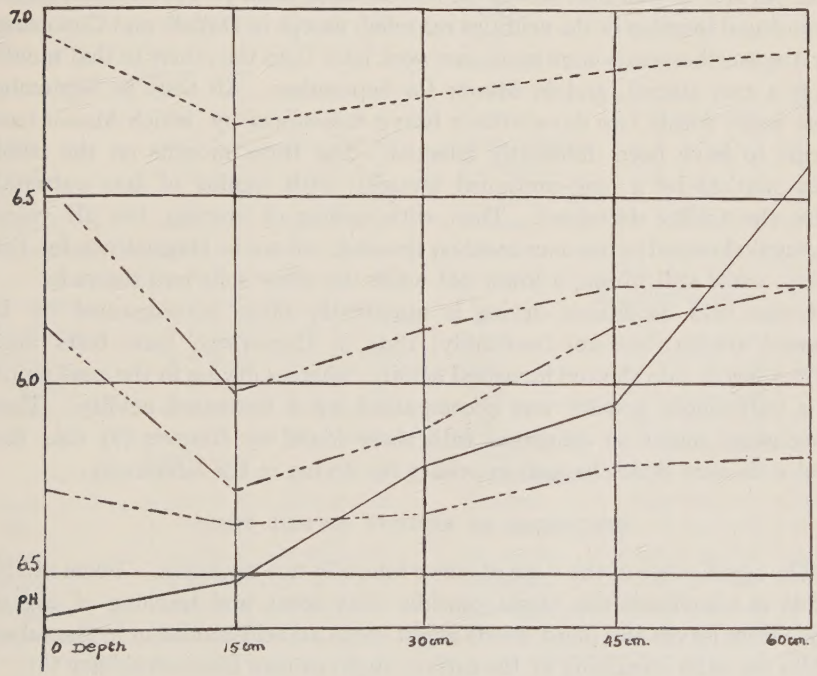

FIG. 1. GRAPHS SHOWING VARIATIONS IN ACIDITY WITH DEPTH

---------- Hagerstown Loam.
—·—·—·— Chester Loam.
—··—··—·· Manor Loam.
—·—·—·— Dekalb Loam.
———— Conowingo Loam.

show a steady rise from the acid side towards neutrality as most previous work would indicate but that there is a drop in pH to about 15 cm., rising then at lower levels towards the neutral point,—a type of curve found by Arrhenius at Bahtim, Egypt. This drop is small in limestone soil; in the others we find that the successive curves between 0–15 cm. describe as it were an arc—somewhat like an opening fan—as the surface soil acidity increases faster than that of the subsoil, until the curve shows a steady decrease from surface downwards. In all cases there is a rise of the pH value at lower depths towards neutrality; this is markedly so in Conowingo. A general statement, then, regarding subsoil acidity can not be made for all but for particular kinds of soil, except that at lower depths the reaction approaches neutrality.

MONTHLY SOIL TESTS

Values obtained from monthly tests made in the same locality for one year are given in table 3. The reader will note that there is no fixed pH value for any particular portion of soil, and that the change from the mean is not large. It amounts at times, however, to pH 1.0 during the growing season, in the subsoil as well as at the surface, hence the plants growing in these places can not be appreciably injured by small variations in acidity.

It will also be seen that during the late summer, from July to October, there is a continual increase in the acidities recorded, except in Dekalb and Conowingo for August (these tests were made one week later than the others in that month, after a rain storm), and in Manor for September. All tests in September were made within two days, after a heavy rain-storm by which Manor loam seems to have been differently affected. The three months on the whole were marked by a long-continued drought; with coming of late autumnal rains the acidity decreased. Then, with coming of freezing, the pH values was again lowered to rise once more on thawing; we see in Hagerstown for February, while still frozen, a lower pH while the other soils had thawed.

Under field conditions drying is apparently often accompanied by increased acidity, but not invariably; thus in Conowingo loam tests made after a heavy rain showed increased acidity, whereas drying in the next month to a pulverulent powder was accompanied by a decreased acidity. These conclusions might be compared with those found by Burgess (3) viz., that acid soils were little changed in acidity by drying in the laboratory.

DISCUSSION OF RESULTS OF SOIL TESTS

The significance of the type of curve found is not apparent. From studies made in woodlands one might consider that decay and leaching of organic acids from leaves and plant debris might cause an acid condition in the subsoil while the salts remaining at the surface might cause a lessened acidity (5). A recent paper (9) attempts to show that facies of a formation determine the reaction of the soil upon which they grow by the different amounts of acid-formers liberated from their decaying leaf-litter.

But the same type of curve is found under old sod where there should be but little leaching, and in cultivated fields where there should be almost none.

TABLE 3

Results of monthly tests, April, 1922–March, 1923

MONTH	REACTION AT VARIOUS DISTANCES FROM SURFACE				
	Surface	15 cm.	30 cm.	45 cm.	60 cm.
	pH	*pH*	*pH*	*pH*	*pH*
Hagerstown loam					
April	7.0	6.9	6.7	6.6	6.8
May	7.0	7.3	7.3	7.4	7.5
June	7.0	6.6	6.9	7.0	7.1
July	7.0	6.7	7.0	7.0	7.0
August	7.0	6.6	6.6	6.6	7.0
September	6.6	6.3	6.3	6.4	6.6
October	7.1	6.8	6.6	7.0	6.9
November	7.3	7.0	7.2	6.9	7.1
December	6.4	6.0	6.0	6.0	6.0
January	7.0	...	6.8	6.7	7.0
February	6.8	6.8	6.5	6.6	6.6
March	7.0	6.8	6.8	6.8	7.0
Chester loam					
April	6.2	6.0	6.3	6.4	6.5
May	6.8	6.2	6.4	6.5	6.4
June	6.0	5.9	6.2	6.6	6.7
July	6.6	5.8	6.1	6.0	6.3
August	6.6	6.3	6.1	6.4	6.5
September	6.0	5.8	6.0	6.0	6.1
October	6.8	6.5	6.7	6.8	6.8
November	6.7	6.0	6.1	6.2	6.3
December	6.1	5.6	5.7	6.3	6.3
January	6.4	6.3	5.8	5.7	5.8
February	7.0	6.8	6.8	6.9	7.0
March	6.9	6.4	6.6	6.8	6.8
Manor loam					
April	6.3	5.4	5.6	5.8	5.8
May					
June	6.2	5.5	6.0	6.1	6.2
July	6.4	5.7	6.5	6.6	6.5
August	5.6	5.2	5.2	5.0	5.0
September	6.2	5.9	6.0	6.2	6.3
Manor loam—Continued					
October	5.6	5.4	5.6	5.7	5.8
November	...	...	...	...	...
December	5.5	5.3	5.7	5.8	5.9
January	5.9	5.7	6.0	6.0	6.0
February	6.6	6.2	6.8	6.8	6.8
March	6.4	6.0	6.2	6.4	6.6
Dekalb loam					
April	5.8	5.4		5.0	4.8
May	5.6	5.7	5.6	6.0	5.7
June	5.4	5.7	5.6	5.4	5.4
July	5.7	5.3	5.3	5.3	5.5
August	5.8	5.9	5.9	6.0	6.2
September	5.6	5.7	5.4	5.6	5.6
October	5.9	5.4	5.8	5.7	4.9
November	6.1	6.0	6.3	6.4	6.2
December	5.6	5.1	5.1	5.3	5.3
January	5.7	5.3	5.4	5.4	5.5
February	6.1	5.4	5.4	5.6	5.9
March	5.8	6.0	6.0	6.4	6.5
Conowingo loam					
April	5.6	5.7	5.8	6.0	6.2
May	5.5	5.9	5.8	6.0	6.2
June	5.6	5.4	5.7	5.7	5.9
July	5.0	5.5	5.6	5.8	6.1
August	5.4	5.8	5.9	6.2	6.6
September	5.1	5.1	5.6	5.9	6.1
October	5.9	6.0	6.6	6.0	6.3
November	5.6	5.8	6.0	6.4	6.5
December	5.4	5.3	5.2	5.4	5.5
January	5.0	4.4	5.2	5.4	5.5
February	5.4	5.0	5.6	5.8	5.8
March	5.2	5.8	6.0	6.3	6.4

Table 4 gives the averages of results obtained from forty series of tests made in open fields immediately adjacent to the wooded areas studied for the soil types, made monthly from July to February inclusive.

The curve might result from chemical reactions and adsorption phenomena so that the actual acidity might not appear at the surface, and in the subsoil acid salts set free from their adsorbed condition by an excess of organic acids might be gradually neutralized by basic substances arising from below in the ground water.

From a study of the distribution of microörganisms in the soil as given by numbers of workers (7) it seems that in general these are found chiefly in the first 16 cm. of soil, with comparatively few below 90 cm. It would seem also that bacteria, protozoa and some algae are to be associated with a soil reaction near neutrality while fungi are more frequently found under acid conditions. It was shown further by Moore (8) that in some soils bacteria had been found at the surface whereas fungi were in lower levels of the same soil. In the soils studied fungi were practically absent from Hagerstown loam, not uncommon in Chester, becoming very abundant in Conowingo loam where they formed with roots a dense mycorhizal mass knitting the leaf-litter together. While microörganisms may have no relation to soil

TABLE 4

Average reactions of cultivated soils

SOIL TYPE	REACTION AT VARIOUS DEPTHS FROM SURFACE				
	Surface	15 cm.	30 cm.	45 cm.	60 cm.
	pH	*pH*	*pH*	*pH*	*pH*
Hagerstown	6.84	6.62	6.54	6.68	6.77
Chester	6.36	6.06	6.34	6.36	6.44
Manor	6.15	5.92	6.11	6.26	6.31
Dekalb	5.94	5.85	5.86	6.12	6.25
Conowingo	5.84	6.03	6.06	6.40	....

acidity except as it forms one of the ecological factors to which they are subject, an interesting problem is nevertheless opened for investigation.

RELATION TO ROOT DISTRIBUTION

Soil acidity affects the plant through the roots and study of root distribution is consequently important in any investigation of the effects of hydrogen-ion concentration on vascular plants. There have been excellent works on root distribution, as that of Weaver (11), who traced out entire root systems with the utmost care, finding that herbs and shrubs of the forest floor are relatively shallow-rooted, that almost without exception the bulk of the absorbing system lies within the surface eighteen inches of soil and that even roots of trees have many shallow branches.

The writer has made some observations on roots of woodland species by digging a trench two meters long, a half-meter wide and down to loose rock. Study of tree roots is more difficult in order to make generalizations. Numerous quarries of the region were studied, where freshly loosened faces are con-

stantly exposed, and neatly exhibit the root distribution not only of herbs and shrubs but also of trees. Trees of various species uprooted by windstorms were also observed. All observations indicated the same general conclusion, that most of the absorbing system of woodland plants is near the surface. It seemed questionable even whether trees in general have deeply penetrating tap-roots, and in two soil types they would be practically impossible since bed-rock occurs within two meters of the surface.

An example of root distribution under "average" conditions (in Manor loam) is shown in figure 2, drawn to scale from a surface exposed by an excavation. Most of the absorbing system is within the first 12 cm. with another stratum from 30 to 70 cm. and only occasional fibrous roots below,

FIG. 2. ROOT DISTRIBUTION IN MANOR LOAM

Scale: 1 mm. = 2 cm.

while there is a layer of conducting roots at 15 cm. Absorbing roots would seem to be associated here with soil nearer neutrality. Dekalb soil is shallower and the root system is more compressed, still more so in Conowingo. In Chester and Hagerstown loams apparently absorbing roots are spread deeper in the soil.

Mycorhiza were found abundantly in the lower part of the leaf mold and in the soil (of the above example) to a depth of 15 cm. where they formed a network of white hyphal strands. Mycorhiza were most abundant in Conowingo woodland soil, least abundant in Chester and absent from Hagerstown. Where they were most abundant the reaction curve showed no depression but steady rise from a low pH, a condition found also in sterile pastures.

PLANT DISTRIBUTION

The significance of plants as indicators of soil conditions described by different writers from the beginning of such work has been summarized to 1919 by Clements (4) who has also indicated the relation of various ecological factors to plant species. Of these factors, hydrogen-ion concentration is one. Various factors have been considered as controlling plant distribution; among these relative elevation, degree of shade, slope exposure, soil temperature, soil moisture, soil texture, aeration, carbon dioxide and salt content of the soil, and soil reaction. One has been stressed at one time at the expense of others. In 1920 Arrhenius (1) considered that soil acidity was a primary factor and in 1922 Wherry (14) agreed that soil acidity is of fundamental importance. It would seem that by interaction of many or all of these factors, one of which at some time and in some place may become predominate, there results an ecological environment causing a specific plant association.[2]

This idea of the soil as "a living thing" has been emphasized by Professor John W. Harshberger, to whom the writer is indebted for advice and help during prosecution of this work.

In studying the ecology of the Paoli region the writer, after familiarizing himself with the flora, undertook quadrat surveys in woods of the various soils. A quadrat of 15 meters was chosen since this size is conveniently measured and a block of four quadrats corresponds roughly to the 100-foot quadrat used by some others. Because the region is undergoing suburban change, woodlands often indicate succession stages and quadrat plottings may show quite different results. A comparison of a number is therefore necessary for an appreciation of the real significance of vegetational distribution on that soil.

Facts as to presence and relative abundance of many species on the soil types studied have already been given (6). It is now desirable to present a more detailed comparison of the consocies.

PLANT DISTRIBUTION ON THE SOIL TYPES

Most productive among the soils, Hagerstown loam is largely under cultivation and presents but few areas of woods on any but rocky ledges. Here *Ulmus americana*[3] is the dominant species (with *Acer saccharum* in one region),

[2] The excellent work of Carsten Olsen in Compt. Rend. Labor. Carlsb., v. 15, no. 1, 1923, did not appear in time to be reviewed in this paper. The writer would call attention, however, to emphasis laid upon the necessity of filtration of the soil extract to remove any solid particles which might cause adsorption of the indicator, falsifying the result. But might not the filter paper introduce as serious an error by adsorption? The paper also shows the value of comparing several entirely different soil types, for two similar habitats on one soil type with the same hydrogen-ion concentration may support the same facies, but two similar habitats with the same hydrogen-ion concentration on different soil types may have quite different facies. Hydrogen-ion concentration, then, would not be the controlling factor.

[3] All species names are according to the seventh edition of Gray's Manual.

while *Fraxinus americana* is subdominate and such species as *Juglans nigra*, *Fagus grandifolia*, *Quercus rubra*, *Liriodendron tulipifera*, *Platanus occidentalis*, *Prunus Mahaleb* are sparse or may form families. These grow in open formation, often with an overhead draped and luxuriant growth of *Vitis cordifolia* making a deep shade so that but few of the smaller treee are found, as *Celtis occidentalis* and *Prunus virginiana*, while saplings of the trees noted above are frequently killed. *Rhus toxicodendron* grows characteristically over ledges and forms mats of erect branches on open ground. The bush stratum is almost entirely *Benzoin aestivale*, changing to species of *Rubus* where there is an opening permitting light to strike through. Little leaf-mold is present, leaves quickly decay and the soil often becomes dry and pulverulent in late summer. There is a sparse ground cover of *Geum canadense*, *Agrimone hirsuta*, *Solidago ulmifolia*, *Aster cordifolia*, but on moist shaded (usually north-facing) slopes are families of *Polystichum acrostichoides*, *Aspidium marginale*, *Thalictrum dioicum*, *Hepatica triloba*, *Cicimifuga racemosa*, *Cheilidonium majus*, *Dicentra canadensis*, *Dentaria laciniata*, *Osmorhiza longistylis*, *Hydrophyllum virginicum* and *Nepeta hederacea*, though *Stellaria media* frequently forms a wide-spread evergreen mat.

Some of the ledges are occupied by a dense growth of *Juniperus virginiana*, which also occurs scattered in rocky pastures with *Crataegus crus-galli*. Here *Aquilegia cabadensis* is typically found on the ledges, and where there is less soil, *Camptosorus rhizophyllus* and *Pellaea atropurpurea*. Social groups of *Oxalis stricta Plantago virginica* and *Antennaria canadensis* grow in dry pastures among grasses and sedges.

Proceeding to Chester loam we find *Ulmus americana* is still present but sparse, and *Fraxinus americana* is now dominant, succeeding *Castanea dentata*, the blighted chestnut. *Prunus Mahaleb* and *P. pennsylvanicum* are frequent; *Quercus alba*, *Q. rubra*, *Q. velutina* and *Liriodendron* are found much as on the preceding loam, while species of *Carya* are better represented, especially by *C. ovata*. But all of these species grow in rather close formation with abundant undergrowth, a second story, of *Cornus florida* and smaller shrubs of *Corylus americana*, *Benzoin aestivale* and *Viburnum molle*. *Vitis cordifolia* does not form as luxuriant a growth while *V. labrusca* is more frequent.

More leaf-mold is found with occasional mycorhiza, and moisture is better retained. There are more species of herbs, these forming a close ground cover of *Smilacina racemosa*, *Sanguinaria canadensis*, *Asarum canadense*, *Podophyllum peltatum* and others, later being succeeded by families of *Osmunda Claytoniana*, *Collinsonia canadensis* and *Aster divaricatus*. *Stellaria media* is replaced by *Galium aparine*.

Moisture is usually well retained by Manor soil of woods and there are many species, but because of greater sterility these do not have as luxuriant a growth; the average rate of growth seems to be less.

Castanea dentata was once dominant but has been replaced by *Carya glabra*, *Liriodendron tulipifera* and *Quercus alba*. The last is most noticeable but not

numerically greater; *Q. rubra* and *Q. velutina* are less frequent while we see *Q. prinus* entering as on the less acid side of its range. *Fagus grandifolia* comes next while *Prunus Mahaleb* is apparently on the acid side of its range. As on Chester soil, *Cornus florida* forms the chief part of the second story, with *Acer rubrum*, *Sassafras variifolium*, *Nyssa sylvatica* and *Prunus virginiana* sub-dominate. Facies of the third story are *Benzoin aestivale* and *Viburnum acerifolium; Vitis cordifolia* is still less developed. We see now a true fourth story, of *Vaccinum pennsylvanicum Rhus toxicodendron* and species of *Rubus*. *Smilax rotundifolia* appears as rather a weak growth. There are many herbs as on Chester loam, and there appear ericads, as *Pyrola americana*, *Solidago caesia* and *Aster divaricatus* are typical of the late aestival aspect.

Phases of Manor loam found in ravines resemble more closely Chester loam while on exposed hill-slopes the vegetation is quite different, consisting of sparse and often stunted growth of *Quercus prinus*, *Kalmia latifolia*, *Rhododendron nudiflorum* and other acid-land plants. This phase has not been considered in the study of Manor loam.

There is a resemblance between this acid hill phase of Manor and the hill-side phase of Dekalb loam; the latter also has phases which are more nearly neutral, in ravines, but vegetation does not make the same amount of growth, the formation is more open, and species are fewer. The soil, being sandy with sandy subsoil, does not retain water; an acid leaf-mold is typical, but aeration is usually good. In ravines we find *Quercus alba* and *Acer rubrum* with sparse *Liriodendron* and *Diospyros virginiana*, and considerable shrub-stratum and herbaceous undergrowth. On gentle hillslopes, considered as typical Dekalb, *Q. alba* is still dominant but *Castanea dentata* was once as numerous; *Q. rubra*, *Q. velutina* and *Carya glabra* are sparse. Higher, *Populus grandidentata* and more frequently *Betula lenta* occur. There is no great distinction between second and third stories, *Cornus florida* and *Acer rubrum* tending to form shrub-growths while *Amelanchier canadensis* is a small tree. *Nyssa sylvatica* becomes copious in places. A bush-stratum, chiefly ericaceous, occurs while herbs are sparse in scattered families.

The ericads become more numerous as we ascend, notably *Gaylussacia baccata*, while *Smilax rotundifolia* becomes copious. Above, on the exposed summit of the hill-range, there is an open formation of *Quercus prinus*, a shrub stratum of sparce *Kalmia latifolia* and patches of *Epigea repens*, of *Polytrichum* or *Leucobryum*. The soil is decidedly more acid than the type; this phase as well as the ravine have not been included in the tabulated results.

From this soil we pass to Conowingo where in the true type bed-rock comes almost to the surface. On this shallow soil, moist in spring, baked in summer, is found *Nostoc* while the rocks are damp, and fruiting *Cladonias*, while later *Cerastium velutinum*, *Arabis lyrata* and *Thalinum teretifolium* bloom. Open spaces may be bare in part but are usually covered with *Andropogon scoparius*, *Paspalum pubescens*, *Phlox sublata* and *Aster depauperatus*. On the barrens *Pinus virginiana* and *Quercus stellata* replace it.

Conowingo clay has been treated as the type in this paper; it covers a larger area than the barrens. The soil is a light powder when dry, into which water does not penetrate readily; beneath is a stiff clay. Leaves do not decay rapidly and the partly decomposed remains are knit by hyphal strands; mycorhiza are abundant. Fruiting bodies of species of *Clavaria* and of *Fistulina hepatica* are found while on logs are bracket fungi,—not the Myxomycetes and Gasteromycetes of moisture situations, as of Chester loam and ravines of Manor loam.

Plant growth is slow and species are not numerous. *Quercus alba* is dominant with *Fagus* sub-dominant, the trees never reaching a large size. Other trees as *Acer rubrum* and *Nyssa sylvatica* are slender but not clumped. There is practically no shrub stratum, as we found also in dry phases of Hagerstown loam, but plants representing the fourth story of Manor loam are numerous, being ericaceous. In the acid leaf-mold may be found families of *Mitchellia repens*, orchids (*Cypripedium acaule*) and ericads as *Chimaphila maculata*. This undergrowth is less than two feet high and the woods are open. Quadrat surveys for density of species do not give a true idea of the vegetation for some plants are as numerous as on other loams, but are dwarf in size so that the total weight of vegetation per quadrat may be but a third of that on better soils.

CONCLUSIONS

Soil-acidity is one of the ecological factors in plant growth. It apparently has a difference significance for different species, and is possibly never the independently controlling factor. Its exact effect on the plant and the way in which it exerts this effect is still unsettled.

While different soil types, covered by the same (deciduous forest) formation, show different facies, this seems due to a combination of factors, of which available soil moisture is not an inconsiderable one.

SUMMARY

In order to determine the actual soil acidity in a small area throughout the year, with its effect on root distribution and the ecological distribution of wild plants, an intensive study was made of a region about Paoli, Pennsylvania, in Chester County, including five soil types. Borings were made with a soil auger and the samples thus obtained were tested colorimetrically.

Tests showed that the acidity increases to a depth of about 15 cm. after which it decreases, the increase being greatest in the most sterile soils. Soil acidity seems to be correlated with the productiveness of the soil. Monthly tests reveal that there are slight variations from time to time in the soil acidity of a given spot, and that plants growing here cannot be sensitive to small variations in the acidity. Excessive drying, as in drought, was usually accompanied by an increase in acidity, while heavy rains lowered it; acidity was also

increased during freezing. Decay and leaching does not offer a sufficient explanation for the type of curve found, for the same type was found in agricultural soils.

Absorbing roots were found chiefly in the least acid portions of soil, associated with fungi as mycorhiza in the top 15 cm. of the more acid soils, the mycorhiza becoming less abundant in the more nearly alkaline.

Descriptions of consocies of the soil types are given, indicating a correspondence between not only the facies, but the whole flora, and its habitat.

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